# Appendix B

# Hydraulic Testing Results

**Table B-1 Pneumatic Slug Test Summary Sheet**

| | DTW (ft below TOC) | TD (ft below TOC) | Saturated Thickness (ft) | Depth to Top of Well Screen (ft below WT) | TOS (ft below TOC) | Stick Up (ft above GS) | TOS Plus 2 ft Safety Buffer | Feet Water Available to Displace | Applied PSI | Slug Test Completed | Initial Displacement (ft) | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phase II Gate 2 Wells 12/12/2011 | | | | | | | | | | | | |
| IW2-1 | 17.13 | 35.28 | 18.15 | 8.15 | 25.28 | 2.68 | 23.28 | 6.15 | 2.7 | yes | 2.97 | |
| IW2-2 | 16.97 | 34.91 | 17.94 | 7.94 | 24.91 | 2.33 | 22.91 | 5.94 | 2.6 | yes | 2.24 | several tries |
| IW2-3 | 17.4 | 33.59 | 16.19 | 6.19 | 23.59 | 3.08 | 21.59 | 4.19 | 1.8 | yes | 4.52 | well not holding more than 2 PSI, retried with better result |
| IW2-4 | 16.98 | 35.15 | 18.17 | 8.17 | 25.15 | 2.32 | 23.15 | 6.17 | 2.7 | yes | 6.10 | |
| IW2-5 | 16.96 | 35.05 | 18.09 | 8.09 | 25.05 | 2.32 | 23.05 | 6.09 | 2.6 | yes | | no recovery |
| IW2-6 | 17.03 | 35.06 | 18.03 | 8.03 | 25.06 | 2.35 | 23.06 | 6.03 | 2.6 | yes | 2.16 | |
| IW2-7 | 17.13 | 35.25 | 18.12 | 8.12 | 25.25 | 2.76 | 23.25 | 6.12 | 2.6 | yes | 2.48 | slow recovery |
| IW2-8 | 16.86 | 34.85 | 17.99 | 7.99 | 24.85 | 2.31 | 22.85 | 5.99 | 2.6 | yes | 1.76 | well wont hold more than 1.5 PSI |
| IW2-9 | 17.06 | 35.17 | 18.11 | 8.11 | 25.17 | 2.61 | 23.17 | 6.11 | 2.6 | yes | 2.20 | |
| IW2-10 | 17.29 | 34.69 | 17.4 | 7.4 | 24.69 | 3.19 | 22.69 | 5.4 | 2.3 | yes | | very slow recovery |
| IW2-11 | 17.01 | 34.95 | 17.94 | 7.94 | 24.95 | 2.58 | 22.95 | 5.94 | 2.6 | yes | 2.48 | |
| | | | | | | | | | | | | |
| Phase II Gate 1 Wells 12/13/2011 | | | | | | | | | | | | |
| IW1-1 | 11.78 | 34.25 | 22.47 | 12.47 | 24.25 | 2.66 | 22.25 | 10.47 | 4.5 | yes | | well wont hold more than 2 PSI, recharge less than 0.01 ft after 20 mins |
| IW1-2 | 14.06 | 34.32 | 20.26 | 10.26 | 24.32 | 2.68 | 22.32 | 8.26 | 3.6 | yes | 8.42 | well won't accomidate packer |
| IW1-3 | 14.24 | 34.4 | 20.16 | 10.16 | 24.4 | 2.62 | 22.4 | 8.16 | 3.5 | yes | 2.84 | bicycle pump |
| IW1-4 | 14.03 | 33.89 | 19.86 | 9.86 | 23.89 | 2.79 | 21.89 | 7.86 | 3.4 | yes | 2.72 | failed diffusion test, bicycle pump |
| IW1-5 | 14.02 | 34.15 | 20.13 | 10.13 | 24.15 | 2.64 | 22.15 | 8.13 | 3.5 | yes | 2.68 | successful diffusion test, bicycle pump slugtest |
| IW1-6 | 13.79 | 34.29 | 20.5 | 10.5 | 24.29 | 2.65 | 22.29 | 8.5 | 3.7 | yes | | well wont hold over 1.5 PSI, very slow recharge, no recovery on slug test |
| IW1-7 | 14.27 | 34.33 | 20.06 | 10.06 | 24.33 | 2.68 | 22.33 | 8.06 | 3.5 | yes | 3.72 | bicycle pump |
| IW1-8 | 12.38 | 33.87 | 21.49 | 11.49 | 23.87 | 2.36 | 21.87 | 9.49 | 4.1 | yes | | well wont hold pressure, water recovers slowly after bailing, failed diffusion test |
| | | | | | | | | | | | | |
| Phase 1 Gate Wells 12/13/2011 | | | | | | | | | | | | |
| IW-1 | 11.59 | 30.06 | 18.47 | 8.47 | 20.06 | 1.57 | 18.06 | 6.47 | 2.8 | yes | 7.56 | threaded top. Well wont accomidate packer. |
| IW-2 | 5.72 | 21.86 | 16.14 | 6.14 | | 1.34 | n/a | n/a | n/a | no | | |
| GW-1 | 11.52 | 30.21 | 18.69 | 8.69 | | 1.48 | n/a | n/a | n/a | no | | |
| GW-2 | 11.44 | 29.71 | 18.27 | 8.27 | | 1.71 | n/a | n/a | n/a | no | | |
| GW-3 | 11.34 | 29.38 | 18.04 | 8.04 | | 1.51 | n/a | n/a | n/a | no | | |
| GW-4 | 11.61 | 29.23 | 17.62 | 7.62 | | 1.4 | n/a | n/a | n/a | no | | |
| GW-5 | 11.38 | 29.02 | 17.64 | 7.64 | | 1.37 | n/a | n/a | n/a | no | | |
| GW-6 | 11.56 | 29.22 | 17.66 | 7.66 | | 1.58 | n/a | n/a | n/a | no | | |

**Table B-2 Borehole Dilution Test IW1-5 Velocity**

**Equation 1 (Freeze & Cherry, 1979, p.429):**
**(from Halevy, et al, 1967)**

**v = [W / (n*j*A*t)] * ln(C/C0)**

| | | | | | | |
|---|---|---|---|---|---|---|
| time at conc. C (t): | 236 | min | **0.01** | cm/min | **0.62** | feet/day |
| conc. (Ct) Final | 882 | µS/cm | | | | |
| initial conc.(C0) | 1056 | µS/cm | | | | |
| effective aquifer porosity (n): | 0.22 | | | | | |
| correction factor (j): | 2.1 | | | | | |
| volume of isolated screen (W): | 4706.76 | cm3 | | | | |
| vertical x-sec area (A): | 593.40 | cm2 | | | | |

**Equation 2 - Curve Matching Approach**
(Lamontagne et. al. 2002)

**v = v* / j * n**

| | | | | | |
|---|---|---|---|---|---|
| effective aquifer porosity (n): | 0.22 | **0.09** | cm/min | **4.09** | feet/day |

**Plug in the apparent velocity (v*) obtained from curve matching.**

| cm/min |
|---|
| 0.040 |

**Correction Factor (j):**
(used in both equations)

$\varphi = 4/(1+(\rho1/\rho2)2+K1/K2[1-(\rho1/\rho2)2]$ **2.13**

| | | | | |
|---|---|---|---|---|
| r1 (screen ID) = | 5.25 cm | | (radius of well O.D.) | |
| r2 (screen OD) = | 6.03 cm | | (radius of well I.D.) | |
| | cm/sec | cm/hr | | ft/day |
| K1 = (screen) | 5.29E-02 | 190.5 | | 150 |
| K2 = (formation) | 2.65E-02 | 95.25 | | 75 |

Volume Calculations:

| Fluid-Filled Components | Length (in) | Diameter (in) | Volume (in3) | Volume (mL) | Volume (cm3) |
|---|---|---|---|---|---|
| Flow Cell | | | | 215.00 | 215.00 |
| Tubing: flow cell to T-junction | 29 | 0.325 | 2.41 | 39.42 | 39.42 |
| Tubing: T-junction to down-hole | 60 | 0.325 | 4.98 | 81.57 | 81.57 |
| Tubing: into well | 529 | 0.25 | 25.97 | 425.53 | 425.53 |
| Tubing: inside packer (in) | 34 | 0.25 | 1.67 | 27.35 | 27.35 |
| Tubing: inside packer (out) | 34 | 0.25 | 1.67 | 27.35 | 27.35 |
| Tubing: out of well | 534 | 0.25 | 26.21 | 429.55 | 429.55 |
| Tubing: through pump to flow cell | 29 | 0.325 | 2.41 | 39.42 | 39.42 |
| Well: volume below packer | 23 | 4 | 289.03 | 4736.29 | 4736.29 |
| **Soild Components** | | | | | |
| Copper Tubing | 23.5 | 0.3125 | 1.80 | 29.54 | 29.54 |
| | | | | | 5992 Total |

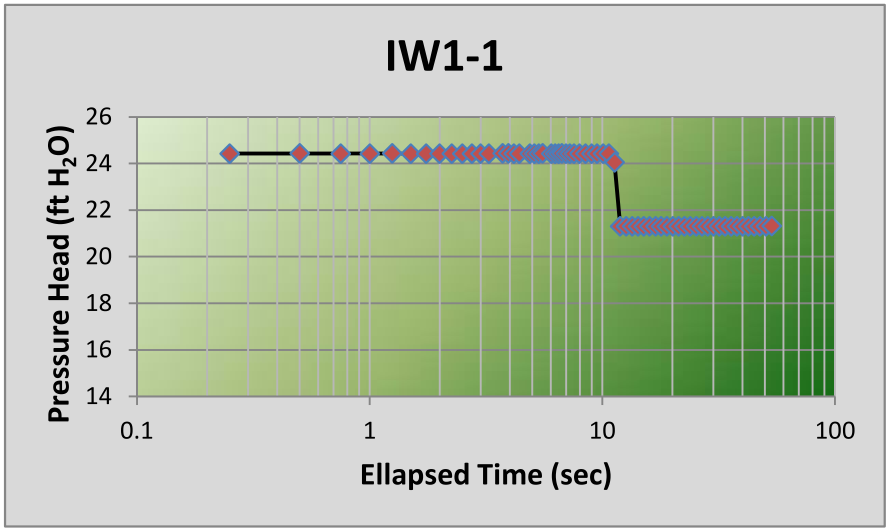
Volume of packered zone = net area (2" OD screen minus mandrel [1/2" OD] influent line [1/4" OD] and inflation line [3/16" OD]) multiplied by 14.25" height of packered zone.

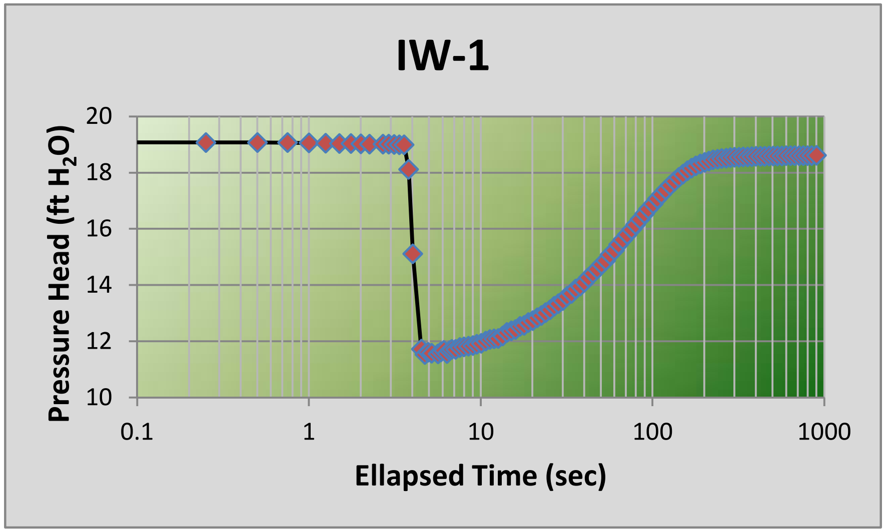
Volume of tubing = 27 feet of 1/4" ID tubing

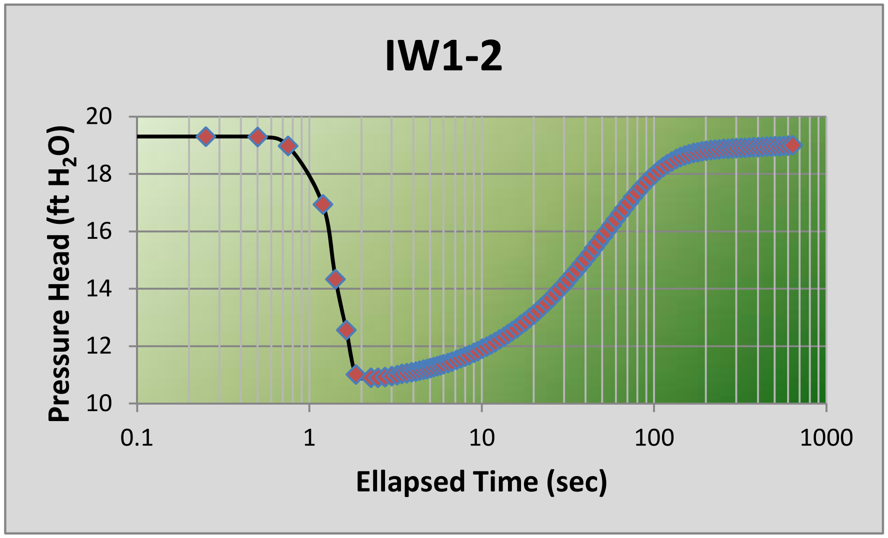
Volume of flow-through cell = approx. 1/12 gallon

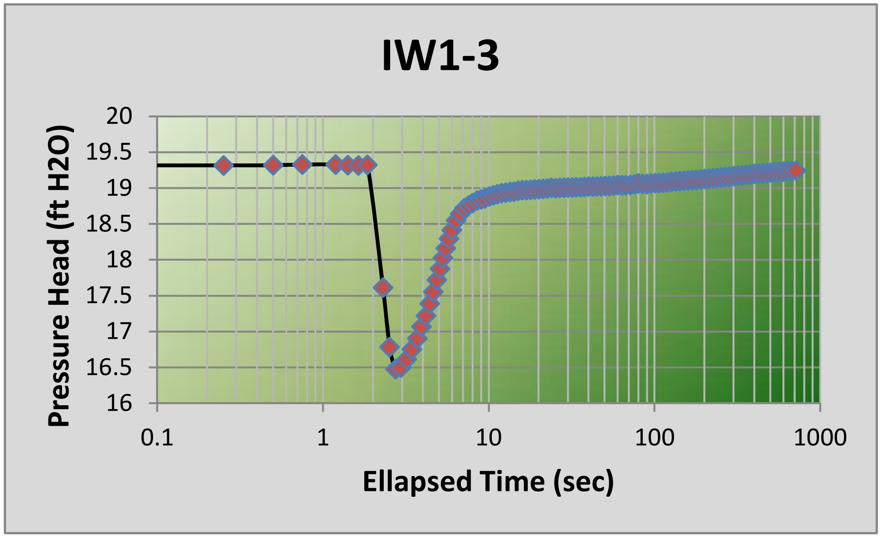
Area Calculations:

Xsec area of packered zone = 92 $in^2$ 593.40 $cm^2$



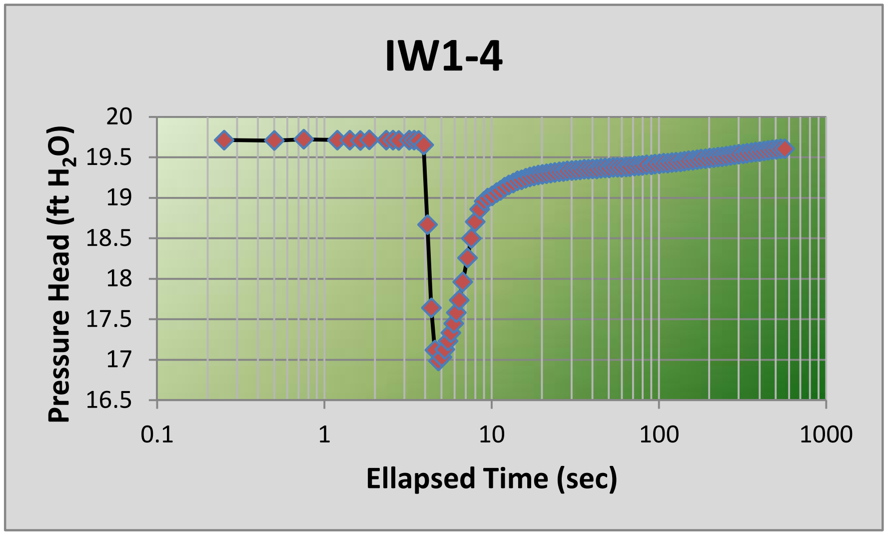



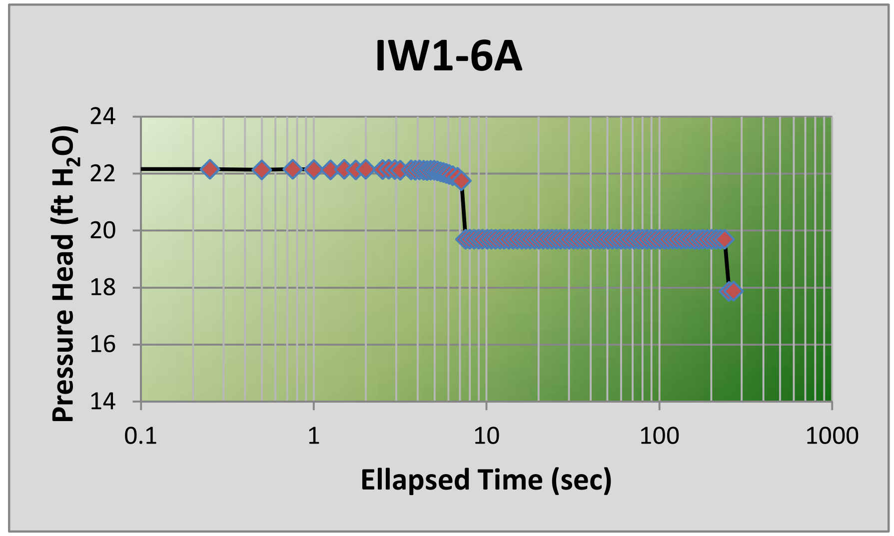



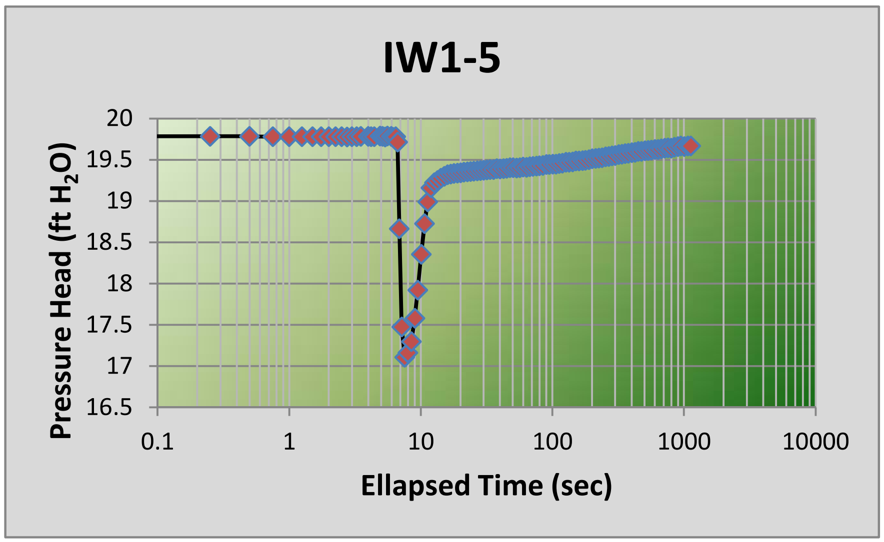

AECOM

| | |
|---|---|
| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | Slug Test Results<br>Phase I Gate, Phase II Gate 1 |

| | | | |
|---|---|---|---|
| DATE: 3/23/12 | DRWN: LG | | FIGURE B-1 |



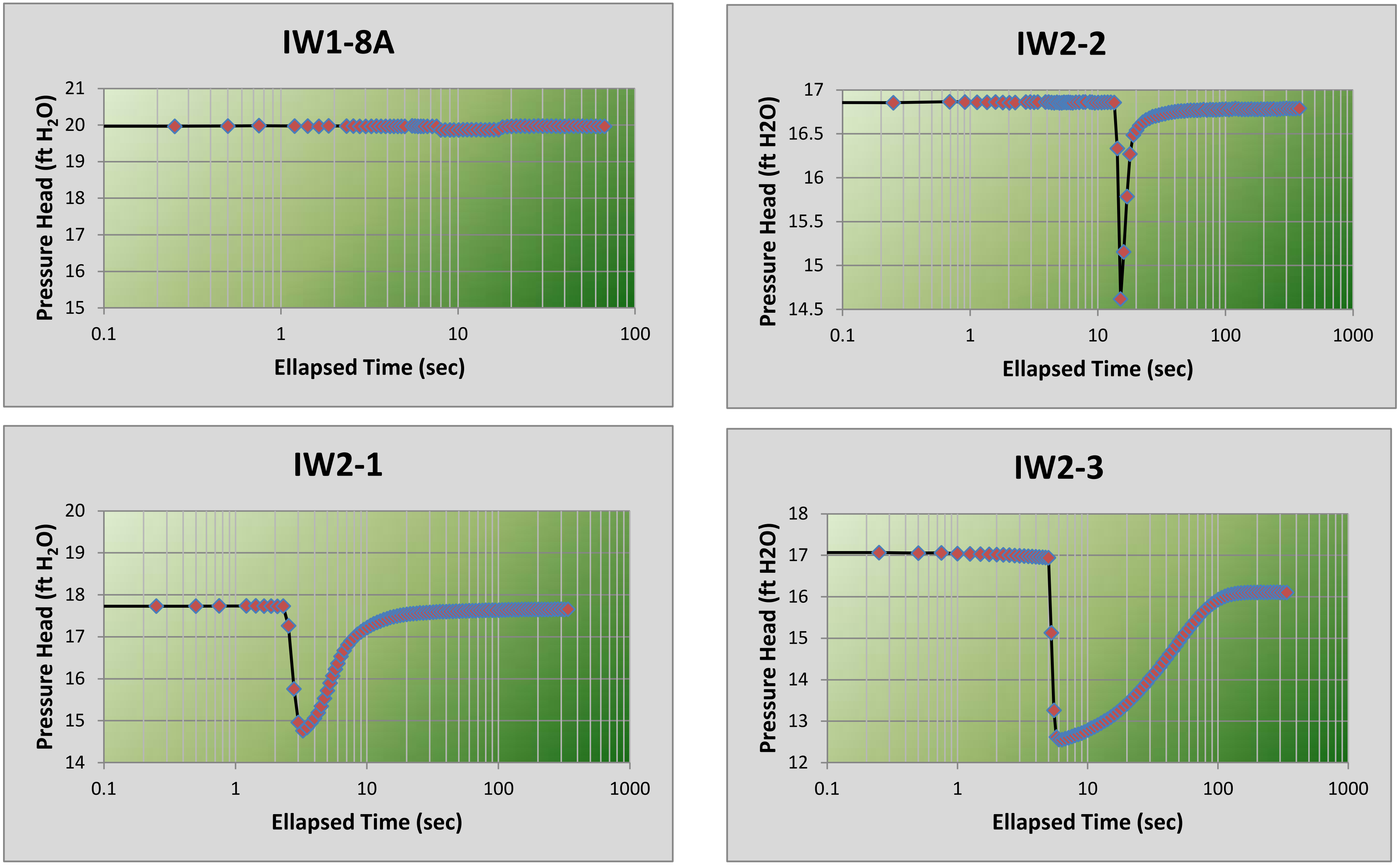





AECOM

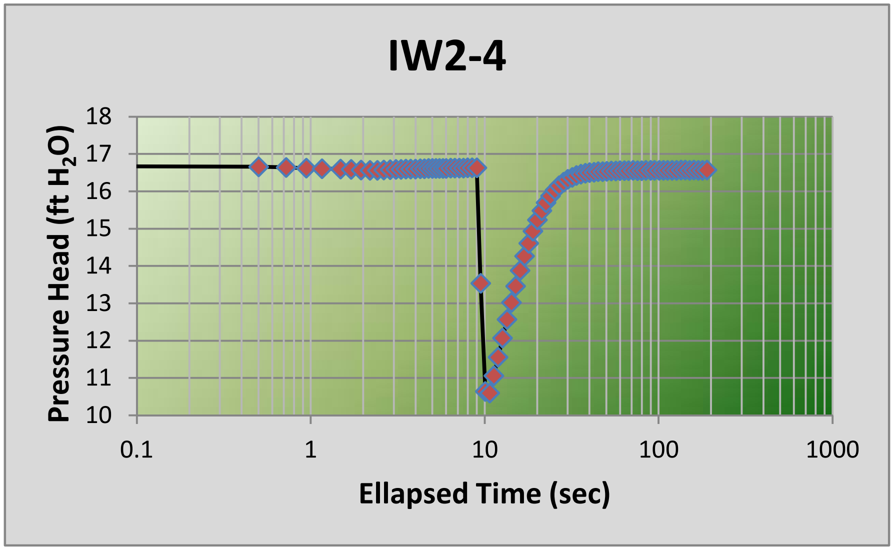
| | |
|---|---|
| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | Slug Test Results<br>Phase II Gate 1 |

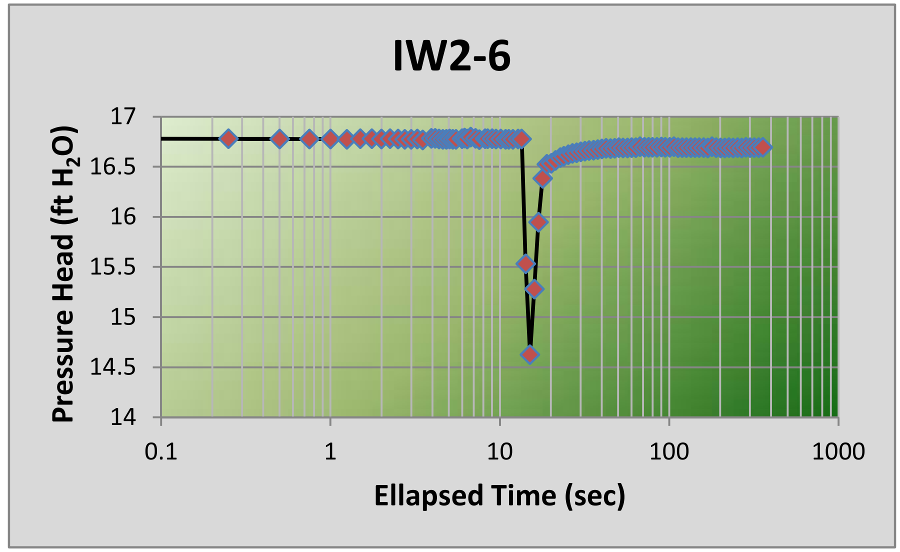
| | | | |
|---|---|---|---|
| DATE: 3/23/12 | DRWN: LG | | FIGURE B-2 |

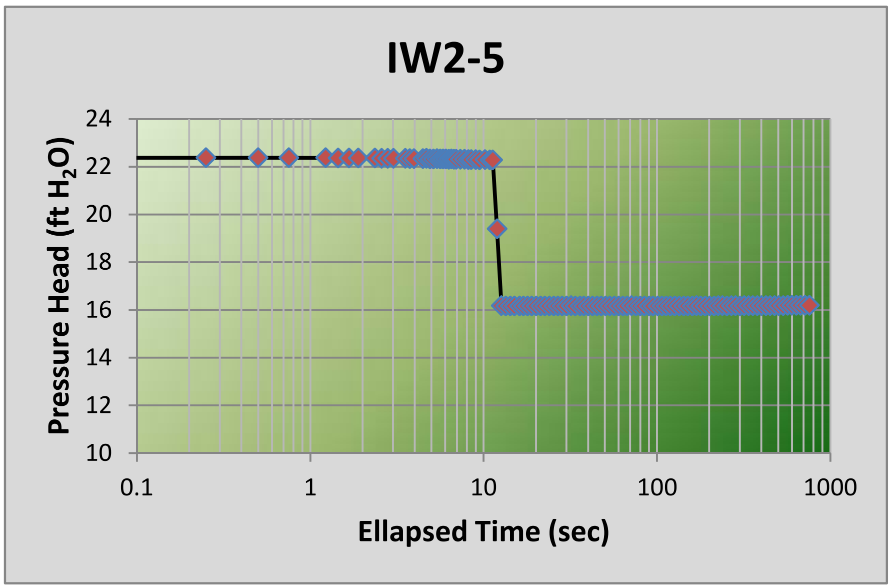


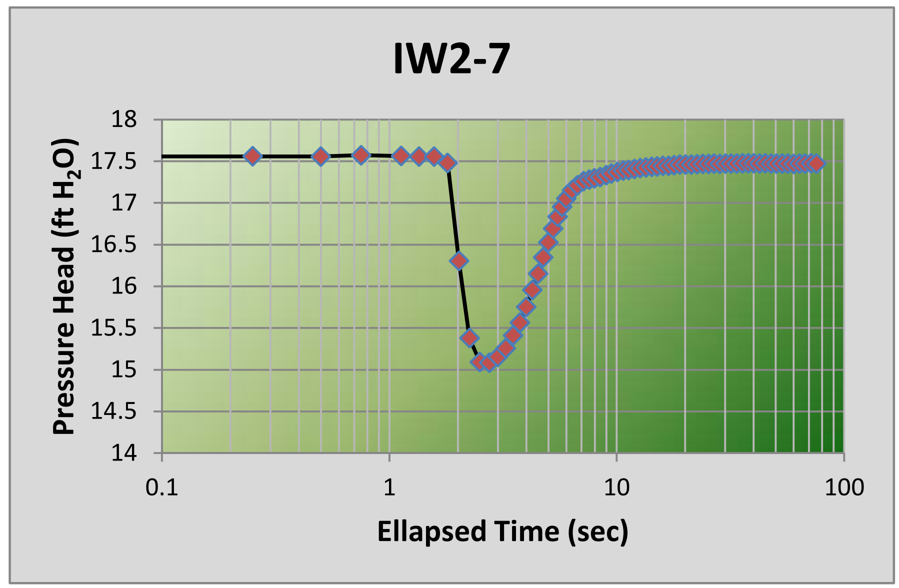

AECOM

| | |
|---|---|
| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | Slug Test Results<br>Phase II Gate 1, Gate 2 |
| DATE: 3/23/12 | DRWN: LG |
| | FIGURE B-3 |



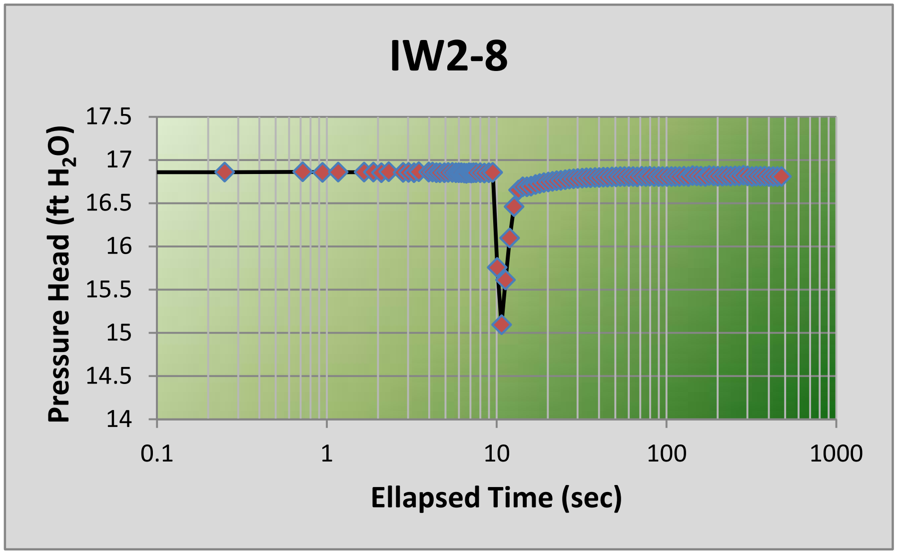



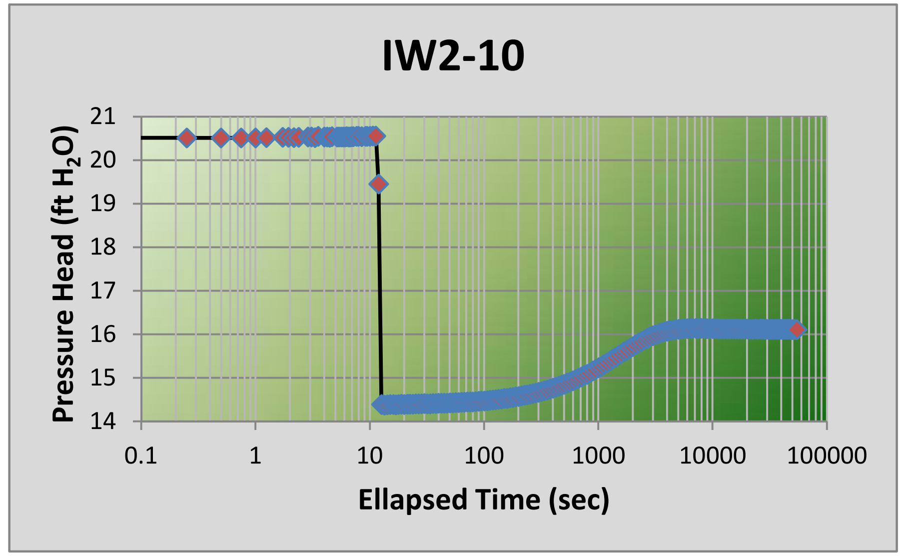



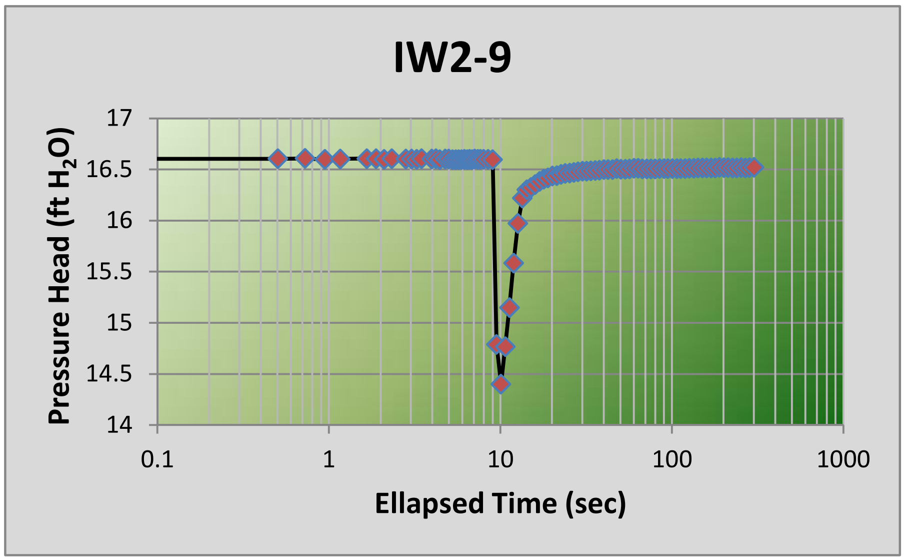

AECOM

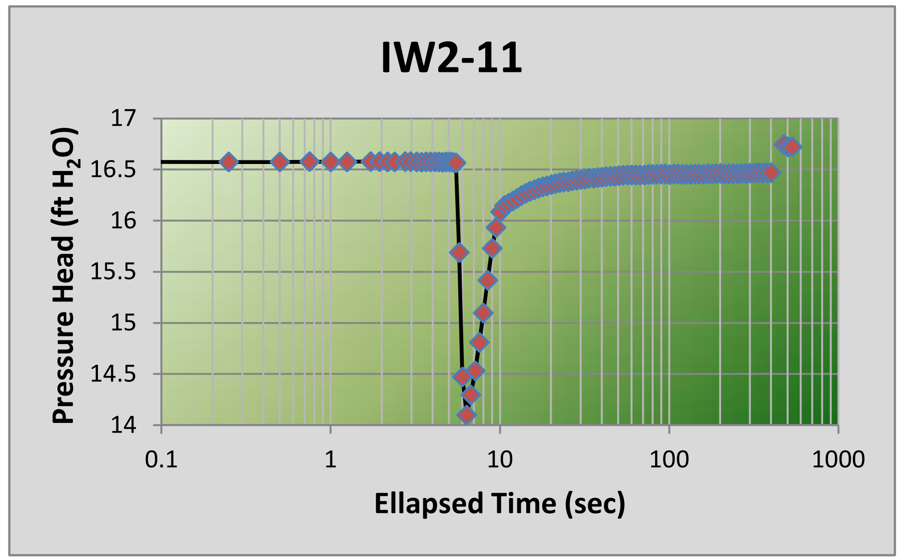
| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | Slug Test Results<br>Phase II Gate 2 |
|---|---|

| DATE: 3/23/12 | DRWN: LG | | FIGURE B-4 |
|---|---|---|---|



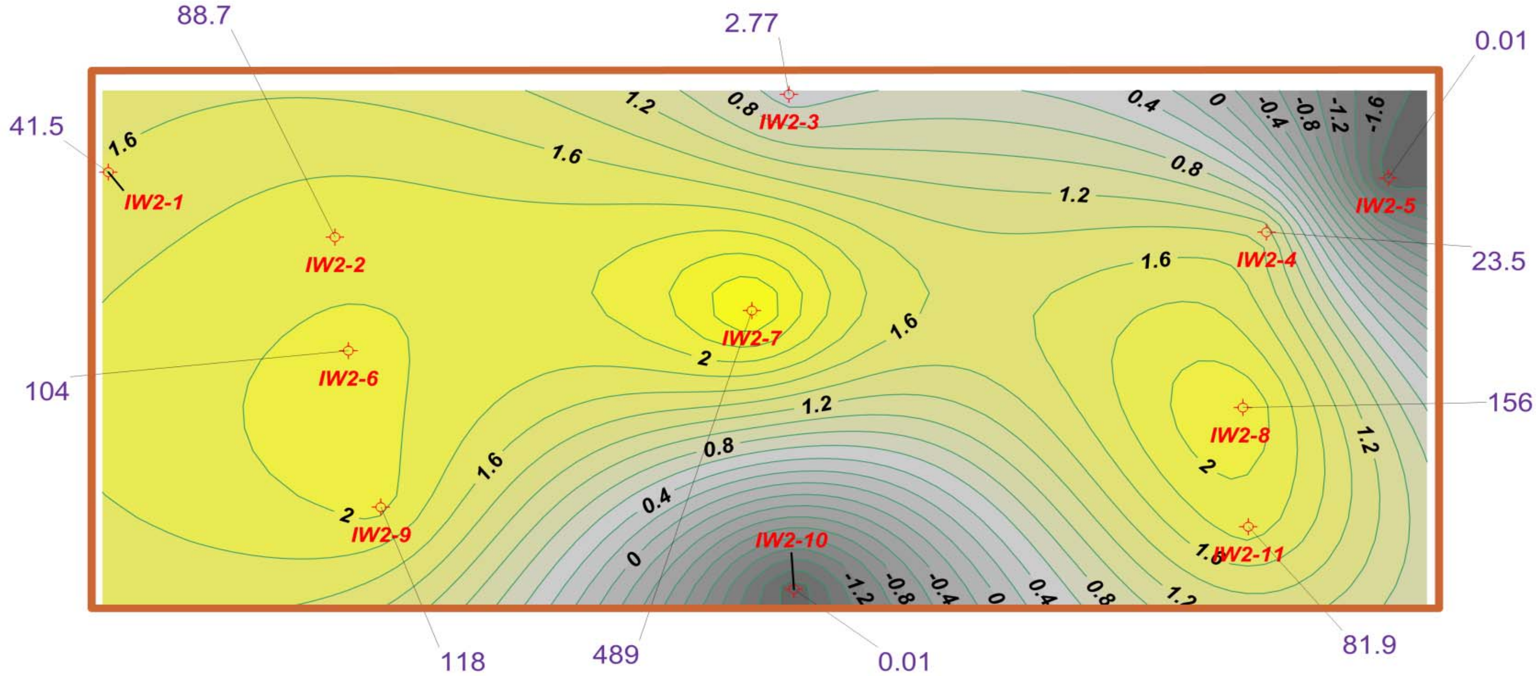




AECOM

| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | Slug Test Results<br>Phase II Gate 2 |
|---|---|

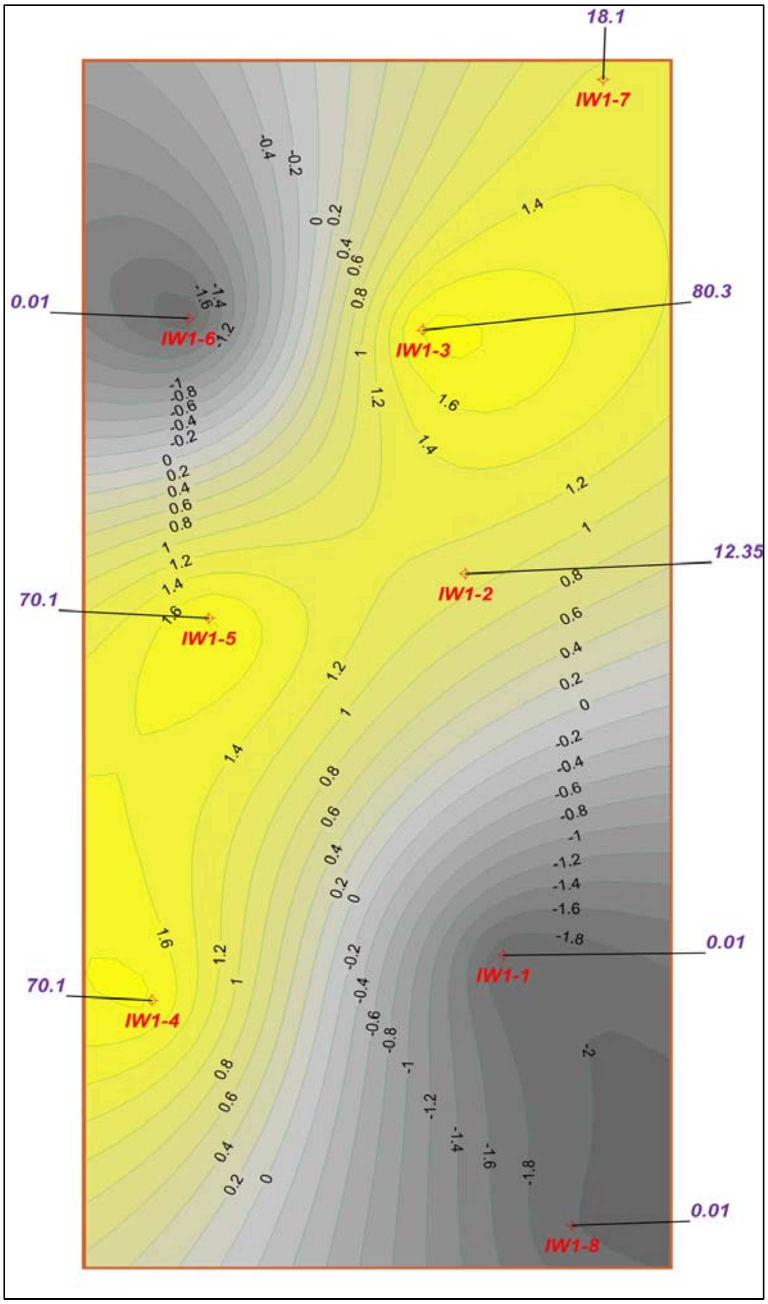
| DATE: 3/23/12 | DRWN: LG | | FIGURE B-5 |
|---|---|---|---|




Note: Spatial Distribution of K is Contoured as the Log of K in ft/d. Labels are Individual Measurements from Pneumatic Slug Testing in Units of ft/d.

AECOM

| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | **Pneumatic Slug Test**<br>**Log K Distribution, Phase 2, Gate 2** |
|---|---|
| DATE: 3/23/12 DRWN: LG | **FIGURE B-6** |



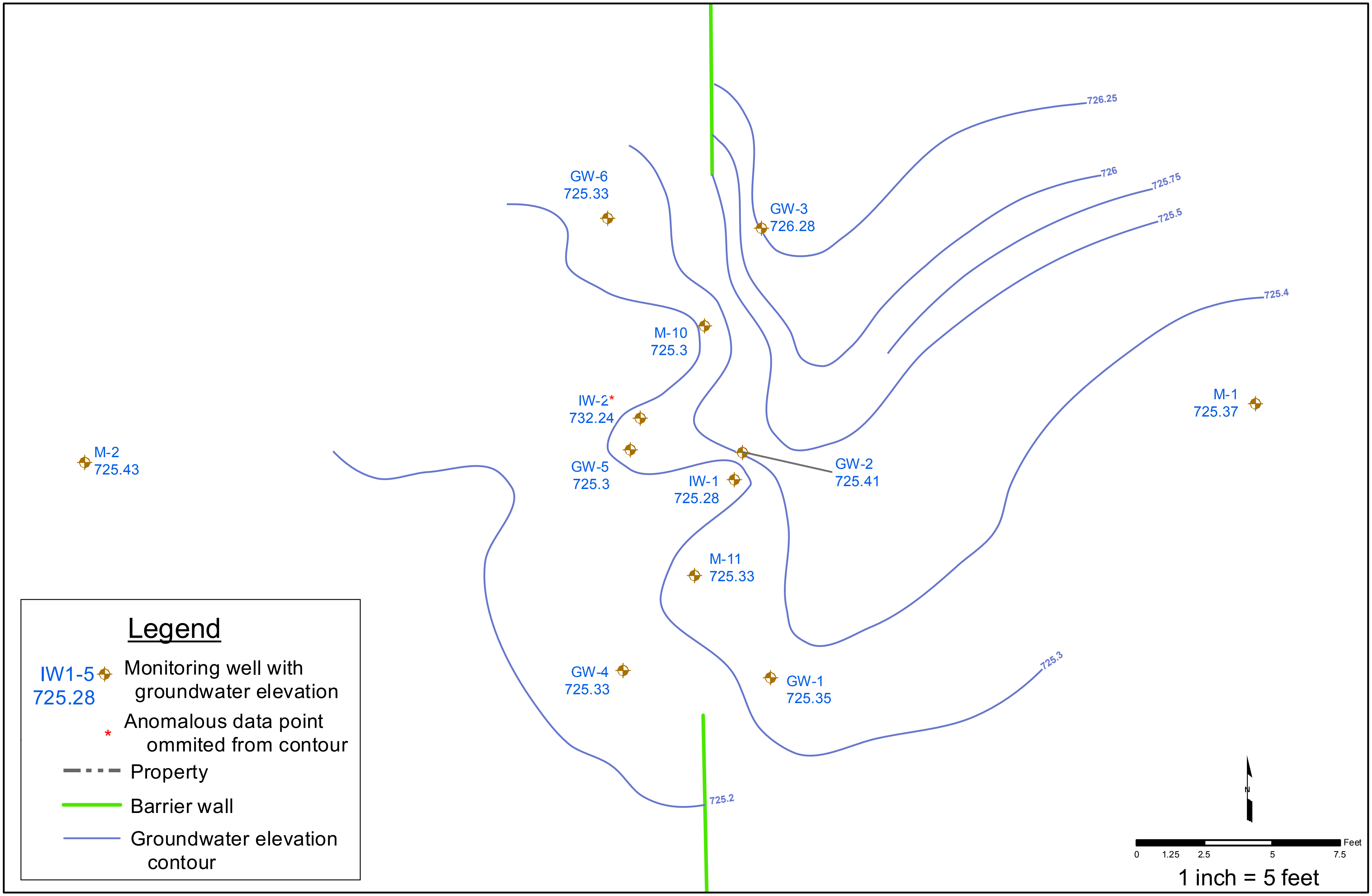

Note: Spatial Distribution of K is Contoured as the Log of K in ft/d. Labels are Individual Measurements from Pneumatic Slug Testing in Units of ft/d.

AECOM

Five Year Review Report
Clean Harbors Coffeyville LLC Facility
Coffeyville, Kansas (60240275.300)

**Pneumatic Slug Test**
**Log K Distribution, Phase 2, Gate 1**

DATE: 3/1/12 | DRWN: LG | **FIGURE B-7**



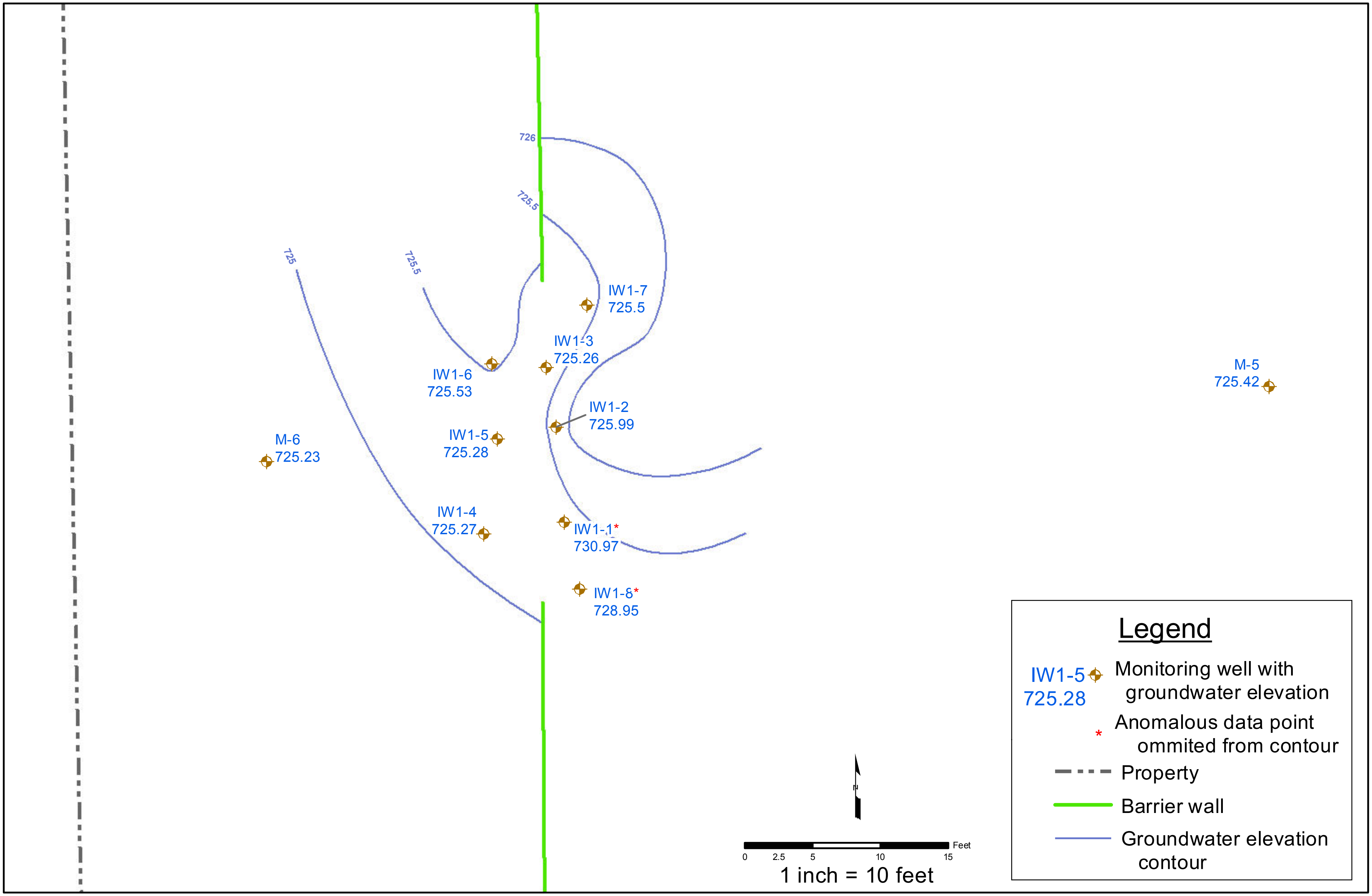

AECOM

CLEAN HARBORS FACILITY
COFFEYVILLE, KANSAS
60240275-300

**Phase I Gate**
**Water Levels - March 2012**

| | | | |
|---|---|---|---|
| Date: 3/15/2013 | DRWN:BR/ftc | Revision: 0 | **FIGURE B-8** |

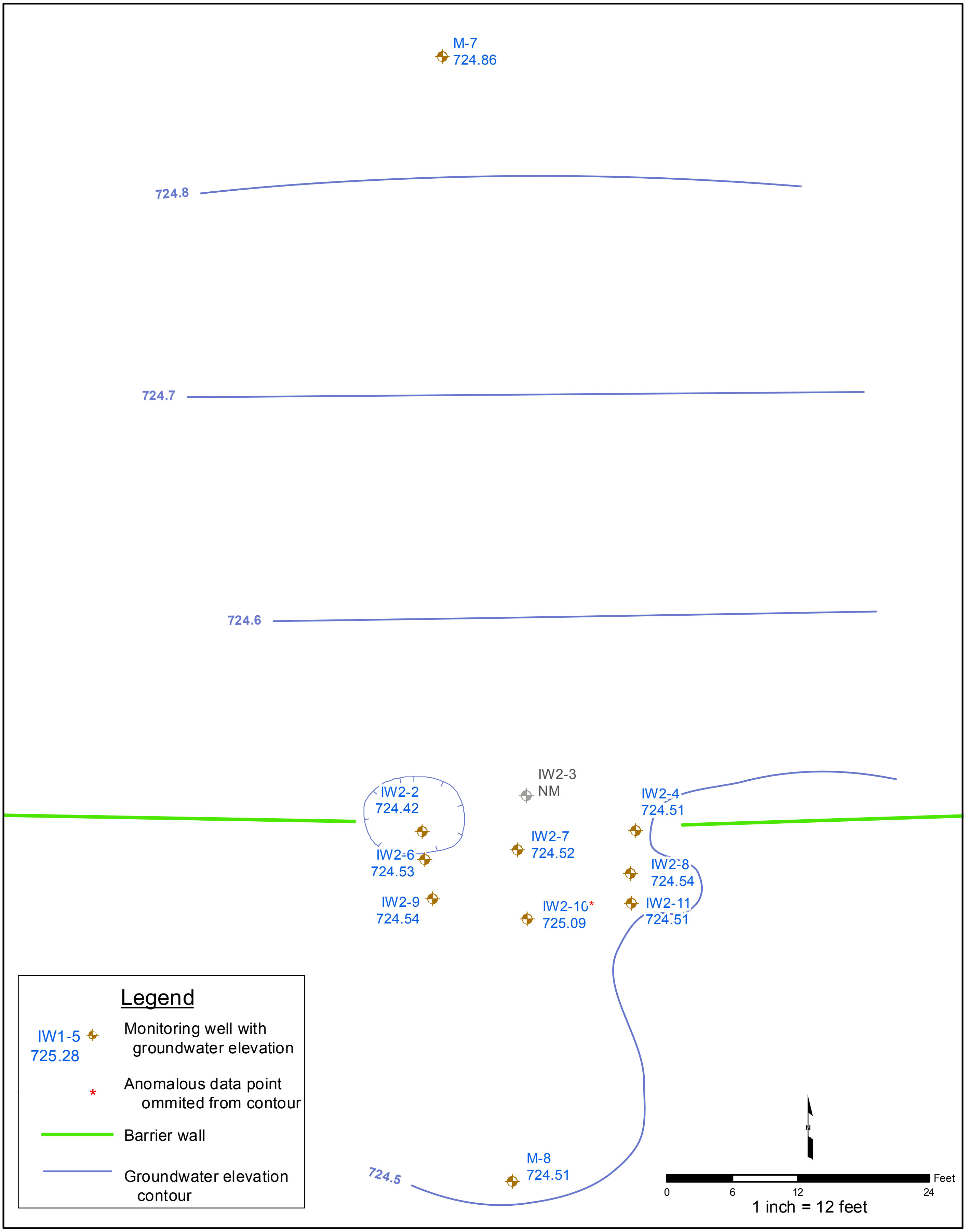
T:\Coffeyville\Projects\Working\SpecialRequests2012\WLE_PhaseIGate.mxd




T:\Coffeyville\Projects\Working\SpecialRequests2012\WLE_PhaseIIGate1.mxd

AECOM

| CLEAN HARBORS FACILITY<br>COFFEYVILLE, KANSAS<br>60240275-300 | | | **Phase II Gate 1**<br>**Water Levels - March 2012** |
|---|---|---|---|
| Date: 3/15/2013 | DRWN: BR/ftc | Revision: 0 | **FIGURE B-9** |




T:\Coffeyville\Projects\Working\SpecialRequests2012\WLE_PhaseIIGate2.mxd

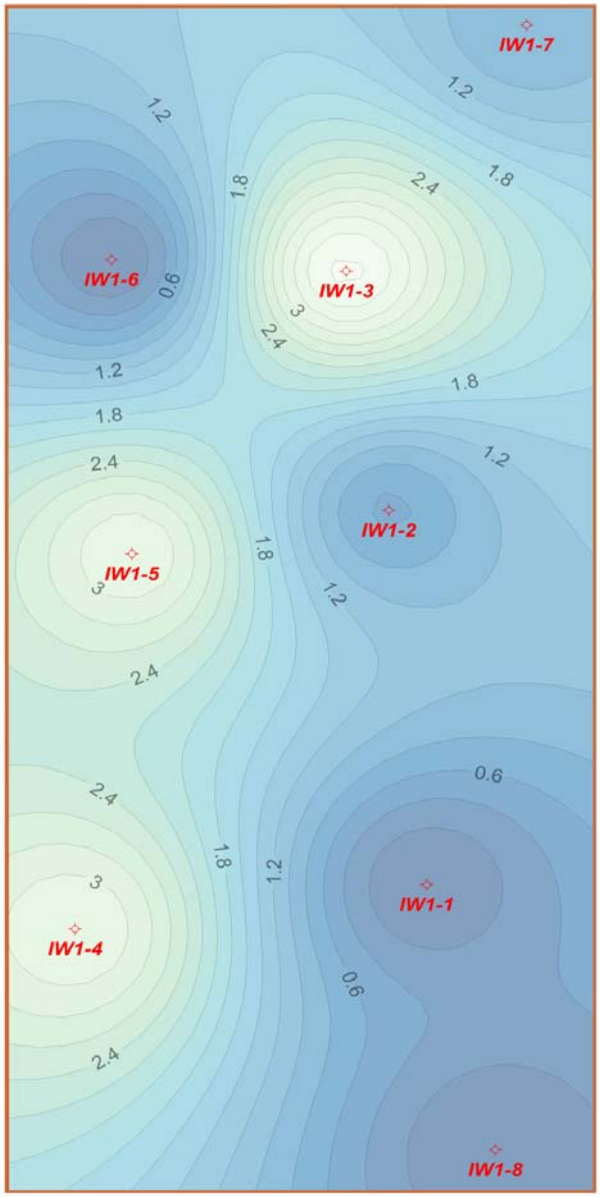
AECOM

CLEAN HARBORS FACILITY
COFFEYVILLE, KANSAS
60240275-300

Date: 3/15/2013 | DRWN: BR/ftc | Revision: 0

**Phase II Gate 2**
**Water Levels - March 2012**

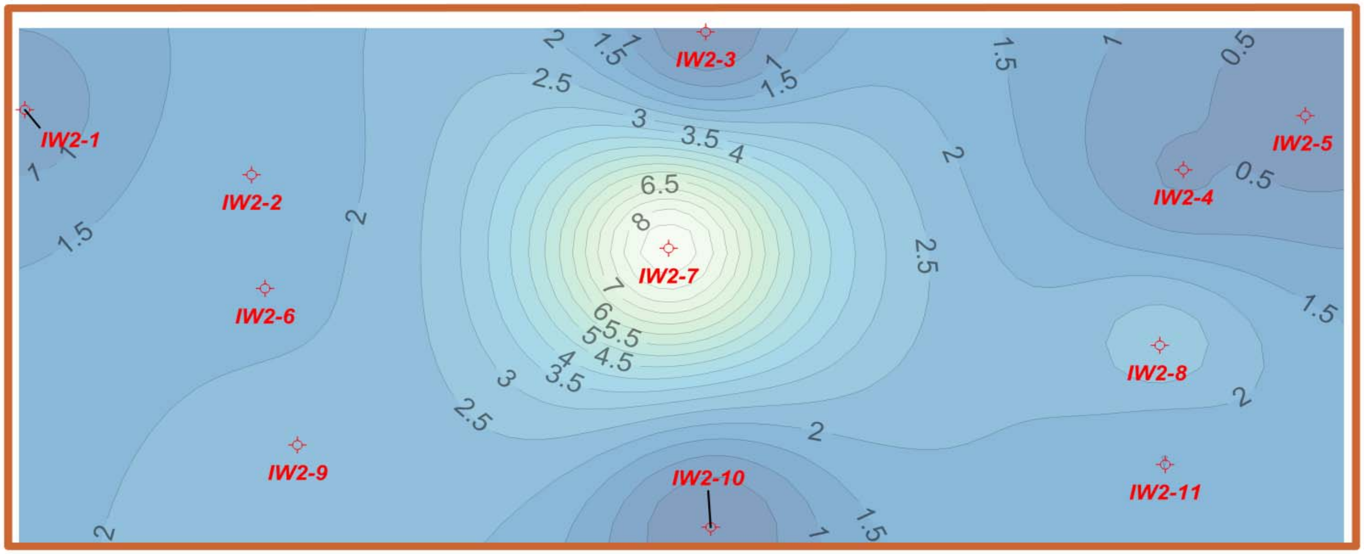
**FIGURE B-10**




Note: Spatial Distribution of Velocity (ft/d) is Calculated Using the Relationship v = Ki/ø
with K being the Hydraulic Conductivity Distribion, I is the Measured

AECOM

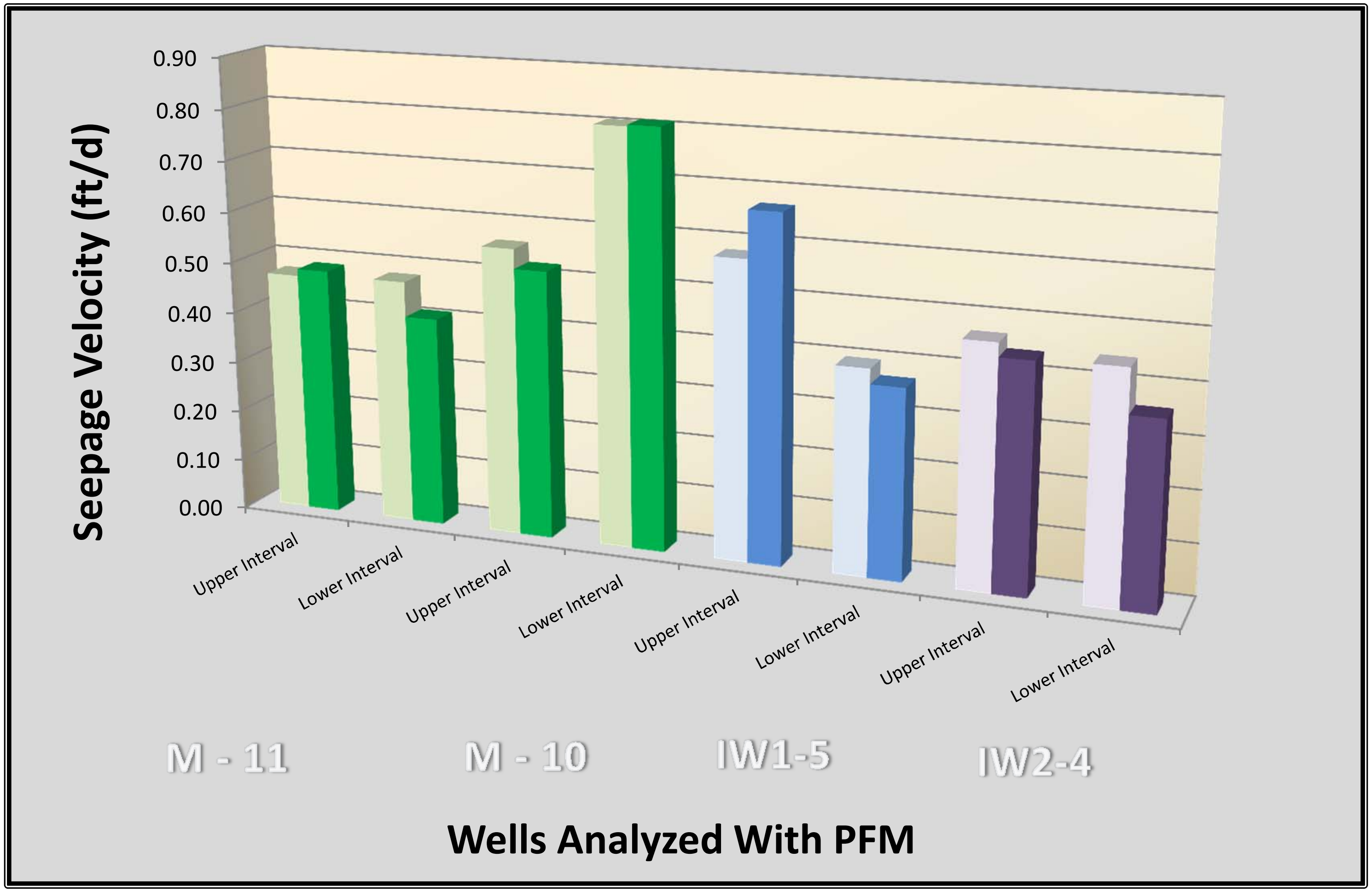
| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | **Velocity Distribution**<br>**Phase 2, Gate 1** |
|---|---|
| DATE: 3/1/12 DRWN: LG | **FIGURE B-8** |




Note: Spatial Distribution of Velocity (ft/d) is Calculated Using the Relationship V = Ki/ø with K being the Hydraulic Conductivity Distribution, I is the Measured Hydraulic Gradient , and ø is the Estimated Effective Porosity.

AECOM

| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | | | **Velocity Distribution**<br>**Phase II, Gate 2** |
|---|---|---|---|
| DATE: 3/23/12 | DRWN: LG | | **FIGURE B-9** |

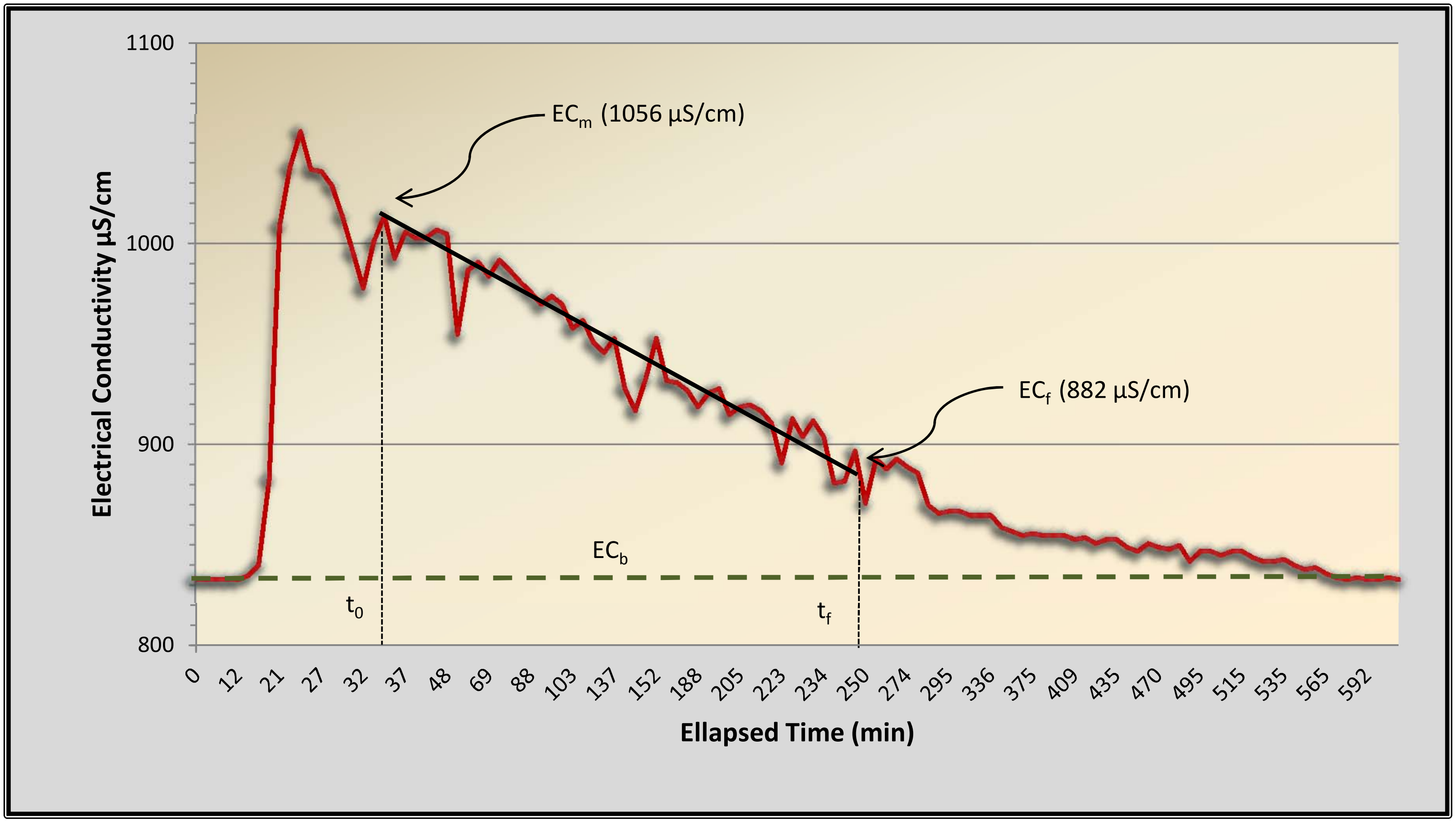



Note: Sample PRMs are 5 feet in Length. Two Placed in Each Well. First PRM Placed on Bottom of Well and the Second Placed Above the First. Two Analyses Completed for Each Interval.

Gate 1, Phase I PRB
Gate 1, Phase II PRB
Gate 2, Phase II PRB

AECOM

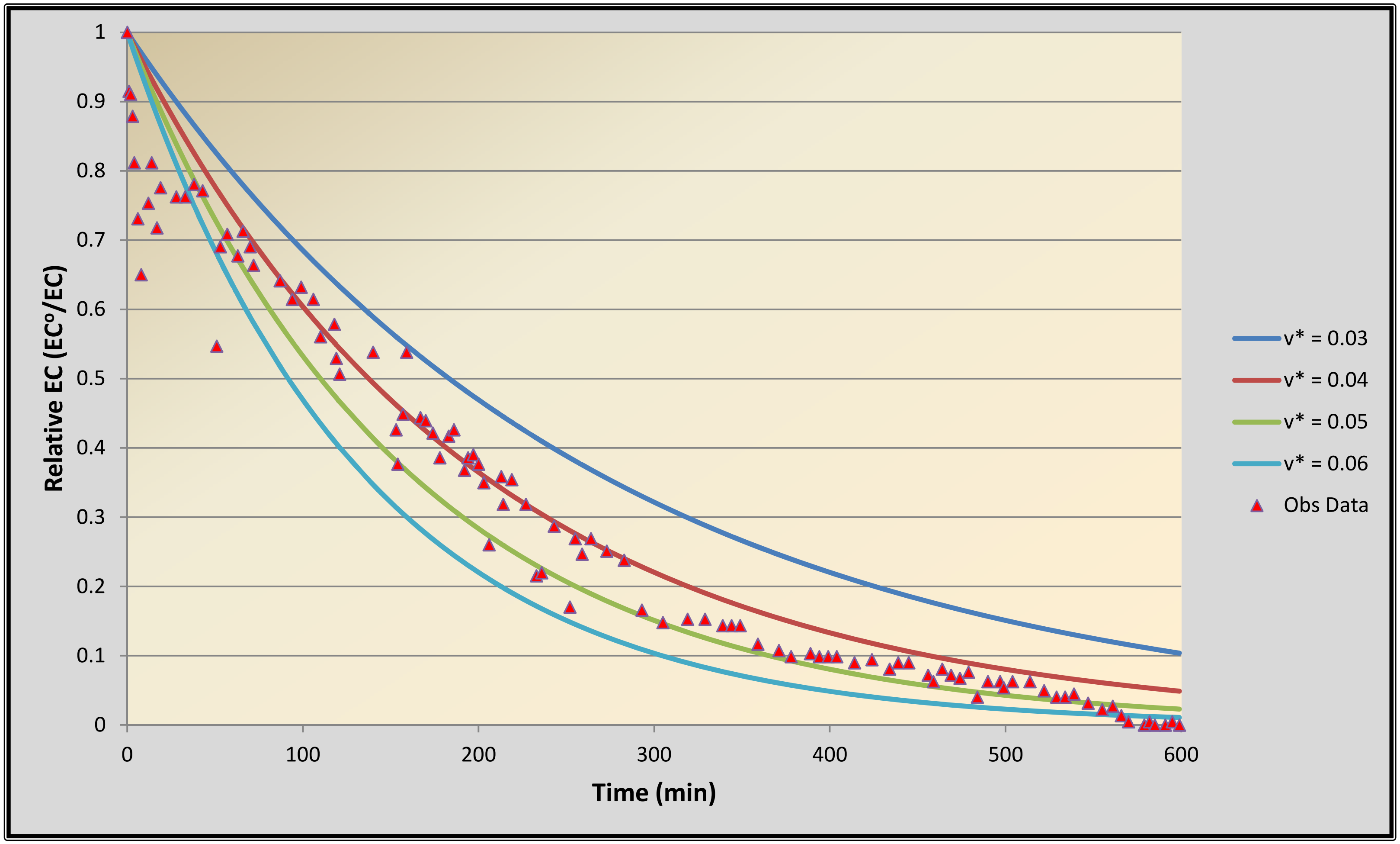
| | | |
|---|---|---|
| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | | PFM Seepage Velocities |
| DATE: 3/23/12 | DRWN: LG | FIGURE B-13 |




Notes: ECb is Background Electrical Conductivity Prior to KCl Injection, ECm is Electrical Conductivity at Arbitrary Initial Time (to), and ECf is Electrical Conductivity at Arbitrary Final Time (tf).

AECOM

| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | IW1-5 Borehole Dilution Test<br>Electrical Conductivity |
|---|---|
| DATE: 3/23/12 DRWN: LG | **FIGURE B-14** |




Note: V* is Apparent Velocity in cm/min.

AECOM

| | |
|---|---|
| Five Year Review Report<br>Clean Harbors Coffeyville LLC Facility<br>Coffeyville, Kansas (60240275.300) | IW1-5 Borehole Dilution Test<br>Theoretical Dilution Curves<br>and Observed Dilution Data |
| DATE: 3/23/12   DRWN: LG | FIGURE B-15 |

# MASS FLUX MEASUREMENTS AT AECOM SITE
# CLEAN HARBORS KANSAS

Prepared for
AECOM

Prepared by
EnviroFlux, LLC

2153 SE Hawthorne Rd.
Suite 117, Box 4
Gainesville, FL 32641
Phone: 352-334-7290

February, 2012

# 1. Executive Summary

Passive Flux Meters (PFMs) were used to measure the ambient groundwater flux at the AECOM site Clean Harbors in Kansas. The wells were located in a permeable reactive barrier and Darcy flux through the barrier was of interest.

The results of the Darcy flux measurements show consistent magnitudes ranging from a low of 1.9 to a high of 4.5 cm/day with a mean Darcy flux of 2.9 cm/day.

# 2. Introduction

Passive Flux Meters (PFMs) were used to measure the ambient groundwater flux at the AECOM site Clean Harbors in Kansas. For a description of PFM fundamentals see Hatfield et al., 2004 and for field implementation see Annable et al., 2005. Flux refers to the mass of water and or contaminants flowing per unit area at a measured point in a well screen averaged over a given period of time. Based upon this general definition, the units associated with mass flux are determined as:

$$flux = \frac{mass}{area \cdot time} = \left[\frac{M}{L^2 T}\right]$$

where the terms M, L, and T represent the base units of mass, length, and time respectively. For consistency with common practice, the ambient groundwater flux will be discussed in terms of the specific discharge or Darcy velocity, which is the volumetric water flux (or flowrate) through a specified cross-sectional area. The resulting units are L/T and for this report the Darcy velocity will be represented with the units of cm/day.

In order to determine the rate of water flow through the PFM, a suite of five tracers were equilibrated on the activated carbon (methanol, ethanol, isopropyl-alcohol, tertiary butyl-alcohol and 2,4 dimethyl-3-pentanol, at concentrations of 1 to 3 mg/g). Following deployment of the PFMs, the fraction of each tracer remaining on the activated carbon, $M_R$, can be used to calculate the specific discharge through the PFM, $q$, using:

$$q = [1.67\ r\ \theta\ R_d\ (1-M_R)]/t.$$

where; $r$ is the radius of the PFM cylinder, $\theta$ is the water content in the PFM, and $R_d$ is the retardation of the resident tracer on the sorbent, and $t$ is the sampling duration. The formulation used in this report assumed that there is no convergence or divergence of flow through the well screen and PFM. The convergence factors are generally near unity but can be estimated using values for hydraulic conductivities of the PFM, screen and aquifer (see Klammler et al., 2007).

## 3. Methods and Procedures

Ten (10) PFMs were constructed and shipped by Fedex to the site for deployment in wells M10, M11, IW1-5, IW2-3, and IW2-4. The first two wells were two inch while the last three wells were four inch diameter. The wells all had a screen interval of 10 feet in length and the PFMs covered this interval. The PFMs were deployed and removed for sampling sampled as noted in Table 1. The average deployment time was approximately 10 days. During installation of the 4 inch PFMs in well 1W2-3, the cable broke on the upper PFM and subsequently neither PFM was retrieved for sampling.

**Table 1. PFM installation and sampling information.**

| Well | Well ID (in) | PFMs Installed | PFMs Sampled |
|---|---|---|---|
| M10 | 2 | 1/20/12 14:15 | 1/30/12 13:05 |
| M11 | 2 | 1/20/12 14:00 | 1/30/12 12:00 |
| IW1-5 | 4 | 1/20/12 13:30 | 1/30/12 14:20 |
| IW2-3 | 4 | 1/20/12 12:30 | Broken Cables |
| IW2-4 | 4 | 1/20/12 11:30 | 1/30/12 15:15 |

## 4. Results

The results of the Darcy flux measurements are provided in Table 2 and Figure 1. The overall data set has a mean of 2.9 cm/day with a standard deviation of 0.7 cm/day for a fairly consistent Darcy flux through the permeable reactive barriers. Only slight differences were observed between the 4 inch wells and the 2 inch wells with a slightly higher mean of 3.1 vs. 2.5 cm/day respectively. Likewise upper and lower zone means were quite consistent with 3.0 vs. 2.7 cm/day means, respectively. In all of the PFM samples measured during this deployment, the remaining tracer value $M_R$ was based on ethanol with an average value of 0.67 that ranged from 0.41 to 0.81. This indicates that about 30% of the ethanol was removed from the PFM by water flow. The $M_R$ values were used for calculating the Darcy flux $q$ using a water content, $\theta$, of 0.55 and a tracer retardation, $R_d$, for ethanol of 27 (Annable et al., 2005).

The results of the Darcy flux measurements can be used to evaluate the permeable reactive barrier performance for site treatment of contaminated ground water.

**Table 2. PFM based Darcy velocities.**

| Well | Darcy velocity (cm/day) |
|---|---|
| M11U-A | 2.2 |
| M11U-B | 2.3 |
| M11L-A | 2.2 |
| M11L-B | 1.9 |
| M10U-A | 2.6 |
| M10U-B | 2.4 |
| M10L-A | 3.7 |
| M10L-B | 3.7 |
| 1W1-5-U-A | 3.9 |
| 1W1-5-U-B | 4.5 |
| 1W1-5-L-A | 2.7 |
| 1W1-5-L-B | 2.5 |
| 1W2-4-U-A | 3.1 |
| 1W2-4-U-B | 2.9 |
| 1W2-4-L-A | 2.9 |
| 1W2-4-L-B | 2.4 |

## References

Annable, M.D., K. Hatfield, J. Cho, H. Klammler, B.L. Parker, J.A. Cherry, P.S.C. Rao, "Field-Scale Evaluation of the Passive Flux Meter for Simultaneous Measurement of Groundwater and Contaminant Fluxes". Environmental Science & Technology. Vol. 39, 2005, pp. 7194-7201.

Hatfield, K., M.D. Annable, J. Cho, P.S.C. Rao, H. Klammler. " A Direct Passive Method for Measuring Water and Contaminant Fluxes in Porous Media". Journal of Contaminant Hydrology Vol. 75, No. 3-4, 2004, pp. 155-181.

Klammler, H., K. Hatfield, M. D. Annable, E Agyei, B. L. Parker, J. A. Cherry, and P. S. C. Rao (2007), General analytical treatment of the flow field relevant to the interpretation of passive fluxmeter measurements, Water Resour. Res., 43, W04407, doi:10.1029/2005WR004718.

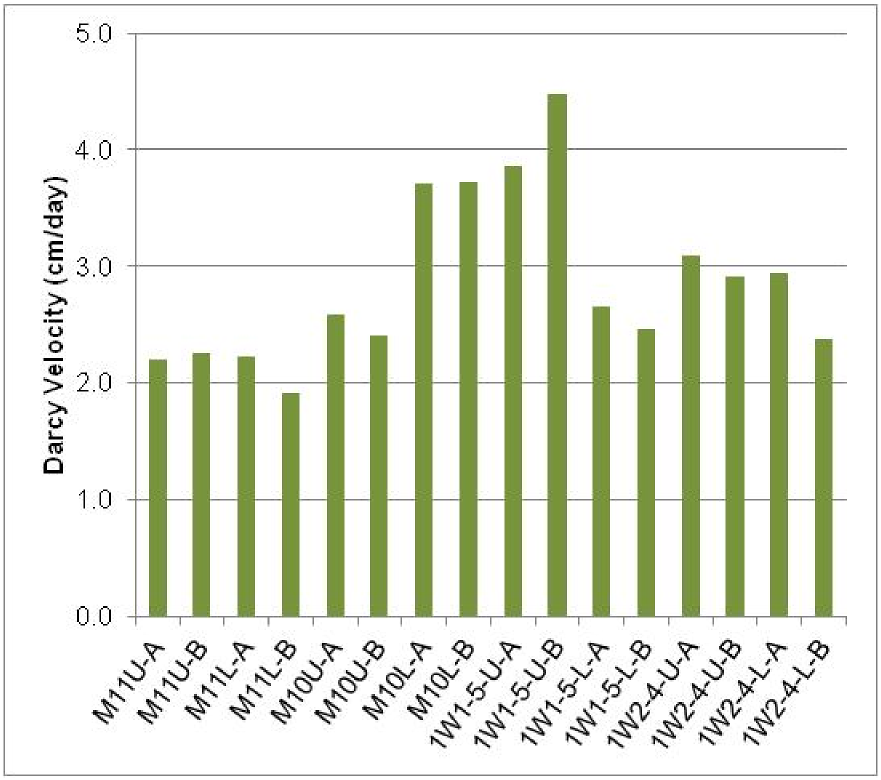



Figure 1. Darcy velocities for all samples.